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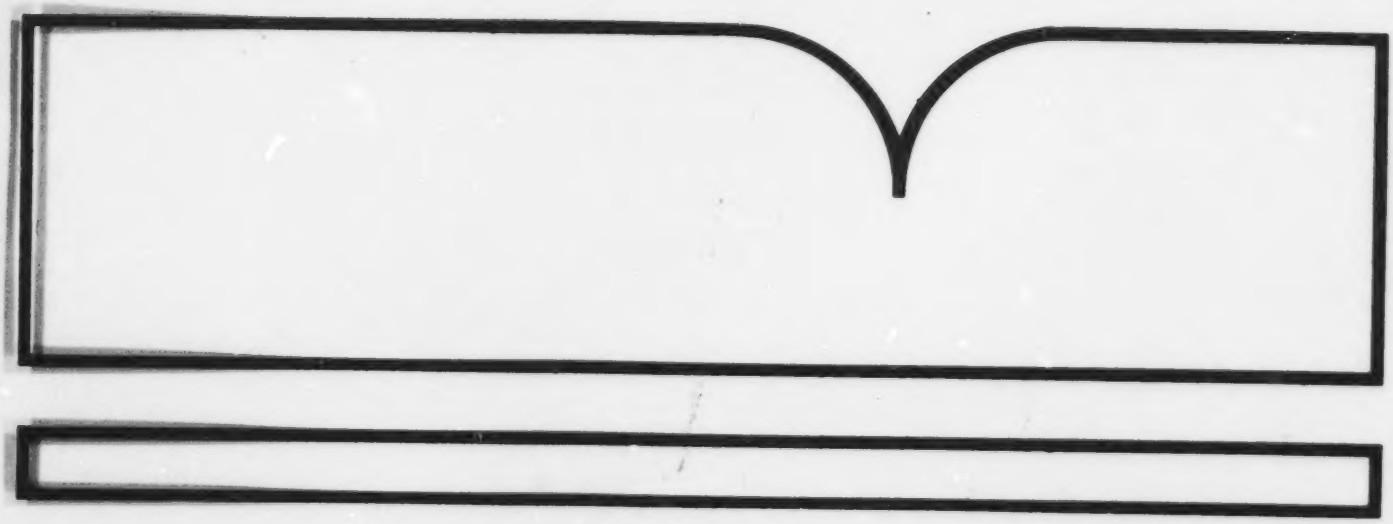

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A Perspective on the Role of Microcosms in Environmental Fate and Effects Assessments

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16. ABSTRACT

This paper provides a perspective on the possible interfacing of microcosm studies with both waste assimilatory capacity determinations and other less quantitative types of assessment. Some of the problems and inconsistencies in the interpretation and application of microcosm results are discussed. Conceptual ideas on how microcosms can be used in quantitative and qualitative risk analysis are presented. Two basic criteria are proposed for the development of the screening microcosm: a.) assurance that the same information cannot be obtained in more simple, laboratory systems; b.) assurance that if the screening microcosm result is not ecologically unique, it is, at least a more sensitive indicator of toxic effects or fate than other laboratory tests. Arguments are presented to support the contention that microcosms, from a quantitative risk analysis standpoint, have no predictive value by themselves. They are instead, representations of the state-of-the-whole of certain ecosystem sections which can be used a means of verifying the environmental significance of other types of laboratory data and the correctness of kinetic expressions used to describe individual fate and effects processes. The microcosm is also a research tool which can enhance our quantitative understanding of the process interactions and metabolic networks typical of natural ecosystems.

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1. Introduction

Comprehensive environmental risk analysis for chemical pollution in aquatic ecosystems must eventually attempt to characterize the waste assimilative capacity of any particular environment; that is, the potential of any environment, from a quantitative standpoint, to accept a certain level of pollution without adverse effects (the definition of waste assimilative capacity differs slightly depending on the application; Cairns, 1981; Campbell, 1981; Goldberg, 1979). A characterization of this type, of course, requires accurate measurements of the rates and dynamics of both fate and effects processes, including their complex interactions. It also requires determinations of how toxic materials will alter these processes quantitatively. This is a significantly separate approach from the current bank of qualitative tests which lead to risk assessments based primarily on relative comparisons of fate and effects test results. Relative fate and effects testing, of which the single-species bioassays and routine biodegradability testing are examples, use "worst-case" and "ranking" criteria to provide concensus measurements of potential adverse environmental effects. Despite the evident success in applying relative fate and effects testing to pollution problems, more attention needs to be directed toward the measurement of waste assimilative capacity.

This emphasis is clearly evident in the risk assessment approach EPA has taken (i.e., determination of "unreasonable risk") in order to meet various responsibilities under TSCA (Federal Register, 1979). Although, current toxicological methodologies concentrate on the effects of chemicals on a few test species or isolated populations, the realistic environmental concern is the effect of these chemicals on natural communities and ecosystems, particularly as they relate to disruptions of the delicate network of

interactions that characterize the function, structure and homeostasis of natural ecosystems. Acknowledging this concern, EPA in conjunction with the Ecosystems Research Center at Cornell University has recently produced a strategy document for implementing a more quantitative research program in ecosystem-level toxicology and environmental fate (Levin, 1982).

A similar concern in the area of environmental fate of chemicals has focused attention on biodegradation studies. Since standard biodegradability or persistence testing procedures do not produce the environmentally relevant information necessary for many current types of risk analysis, research strategies concerned with the determination of biodegradation rate constants, and examination of the site-specific environmental factors which control biodegradation rates, have to be developed and implemented (Haque, 1980; Bourquin and Pritchard, 1979; Maki et al., 1980).

Given this established need for a more quantitative approach to risk assessment in aquatic environments, our paper attempts to illustrate how microcosm studies interface with both waste assimilative capacity determinations (regardless of the appproach taken or endpoints selected) and other less quantitative types of assessments. Problems and inconsistencies observed in the interpretation and application of microcosm results are discussed.

A microcosm study is defined here as an attempt to bring an intact, minimally disturbed piece of an ecosystem into the laboratory for study in its natural state, i.e., the establishment of a physical model or simulation. The confirmation of that piece of the ecosystem within definable physical and chemical boundaries under a standard set of experimental conditions (controlled lighting, humidity, aeration, mixing temperature, etc.) constitutes the microcosm system itself. The microcosm is theoretically meant to harbor a

level of complexity that (a) is representative of that portion of the ecosystem from which it was sampled and (b) cannot be readily duplicated in the laboratory by assembling component parts or by making composites of individuals. It is considered an analog to the field; therefore, studies with a microcosm are surrogates of actual field studies. The simulation capacity of a microcosm is determined by calibration with the field based on criteria established through experimentation and the question to be addressed by research. Ideally this should be done by using measurements that reflect macroscopic, system-level properties that result from integrative coupling among the biological, chemical and physical properties of an ecosystem. Some success has been apparent in this regard with measurements of integrative biochemical properties, such as total CO_2 flux (Ausmus et al., 1978; Van Voris et al., 1980), nutrient cycling (Jackson et al., 1978; Jassby et al., 1977) and pH-Eh or dissolved oxygen relationship (Waide et al., 1980; Giddings and Eddleman, 1978). A more extensive discussion of field calibration is given by Pritchard (1981).

2. Role in Environmental Risk Analysis

The role of microcosm studies in environmental risk analysis is quite explicit, given the definition described above. A schematic representation of this role is shown in Figure 1. Risk analysis is divided into two categories: qualitative assessments and quantitative assessments. Quantitative assessments are synonymous with determinations of waste assimilatory capacity. Qualitative assessments establish risk by comparing test information (fate or effects) for a chemical that is ranked within a data base against a large array of previously tested chemicals by the same, often highly standardized test method. The emphasis, in the latter case, is on screening large numbers of chemicals for information on their fate and effects. This approach requires consistency in test results and expediency in test method implementation.

The test methods are further divided into three levels of organization: (1) single species tests, such as those used in bioassays and certain biodegradation studies; (2) multispecies tests which use inocula (generally isolated populations) from the field in an experimentally convenient manner and generally ignore controlling factors associated with the physical integrity (intactness) of the field samples, natural population interactions, system homeostatis and trophic and biological structure, and (3) microcosm studies (tests) that encompass all of the controlling factors not considered in the multispecies test.

The focus of Figure 1 is the flow of information (indicated by arrows). Single-species tests and many multispecies tests support the qualitative or screening assessment, as would be expected. Many biodegradation studies are examples of multispecies tests in that they use inocula of natural water or sediment in a shake-flask system. Since little regard is given to the natural physical integrity of these microbial communities, the results can only be used for qualitative assessments.

The community settling test of Hansen and Tagatz (1980) is a good example of a multispecies test used for effect studies. In this case, azoic sand exposed to a particular concentration of toxicant is colonized by invertebrate larvae in unfiltered sea water flowing over the sand. Adverse effects are indicated by statistically significant changes in population size and diversity relative to the unexposed controls. Only a qualitative assessment of toxic effects can be made; very few deductions can be made about effects on paper-population dynamics or the permanent or long-term damage to natural benthic communities.

Conceptually, multispecies tests are also the basis for quantitative assessments and predictions when used in conjunction with microcosm studies or actual field studies (depicted by converging arrows in Figure 1). The microcosm serves as the interpretational tool for integrating information from multispecies test systems into predictions of environmental fate and effects. It, in fact, provides the basis for extrapolating multispecies test results to the field. Once this basis is established, the multispecies test, for the particular application being considered, becomes the principal source of information needed for all subsequent quantitative assessments. The microcosm results are of little predictive value by themselves. Their usefulness in quantitative assessments is a direct function of the availability and experimental design of good multispecies tests.

3. Role of Microcosms in Qualitative Assessments

It is necessary at this point to discuss the role of microcosms in qualitative assessments. That is, how are data from a microcosm study used for screening purposes The term "screening microcosms" originated from the fear that simplified fate tests, such as the BOD or river die-away methods and single-species effects tests were not revealing all potential problems brought on by contamination of an ecosystem with a particular pollutant (Harris, 1980). Undoubtedly, these tests lacked complexity. Microcosms seemed superficially capable of filling that void. Two assumptions are crucial to the screening microcosm approach. First, ecosystems as biogeochemical units have measurable properties (Schindler et al., 1980). These properties or ecosystem system-level behaviors reflect the integration of many internal processes and components and their interactions. The ecosystem-level behaviors cannot be inferred or predicted from measurements on isolated components in the laboratory (Weiss, 1971). Since microcosms are essentially analogs to certain pieces or parts of an ecosystem, they should also have measurable ecosystem-level properties.

Second, the measurement of these integrative properties of natural ecosystems or microcosms possesses a degree of consistency and reproducibility which allows toxic effects of a chemical to be distinguished from background noise and allows the effect of these properties on the fate of the chemical to be investigated.

Given these assumptions, a screening program can be set up in which the same type of microcosm is dosed with an array of chemicals, and the resulting fate and effects information compared on a relative basis much like the assessment procedures used for toxicity and biodegradability information. Standardization of the microcosm study eventually will be required under this

type of program. There is no need to extrapolate quantitatively the results to the field; in fact, it is not expedient in light of screening objectives because additional information will be required for extrapolation.

Undeniably, there would appear to be a role for screening microcosms due to current interest in ecosystem-level fate and effects studies (Levin, 1982). But they must be used in correctly and with good foresight. Two criteria are proposed for the development and use of screening microcosms:

a. Care should be taken to assure that the conclusions or risk assessments obtained from a screening microcosm study cannot be obtained in a simpler way. For example, if a chemical is found to biodegrade more readily in a microcosm containing sediment, it may be because the system contains such a large amount of bacteria-ladened sediment. The more simple, shake-flask studies with sediment-water slurries at different sediment concentrations, therefore, may provide the same information as the microcosm. Likewise, if, in a microcosm effects study, a toxic response by a community can be attributed to the response of a single species, then potentially a toxicity test can be developed with that species and the same protective effect on the community realized through the single-species test. In both cases, the microcosm test becomes superfluous. The applicability of synthetic communities studies, pioneered by Metcalf (1971), Gillette (1976) and Isensee (1973) as potential screening microcosms has been criticized (Pritchard, 1981; Branson, 1978) because, in many cases, much of the same fate and effects information apparantly could be obtained in a clearer form with more simple tests.

To be useful, the screening microcosm must provide insight into phenomena or events which are not readily examined or demonstrated in previously established tests. It must be unique enough, for example, to be included in

the "minimum ecological data set" of the water quality criteria program (Federal Register, 1980). The soil-core microcosms developed by Van Voris et al. (1980) and Jackson et al. (1977) represent a unique screening microcosm. These systems permit the screening of chemicals for their interference with the leaching of inorganic nutrient from the soil. It is not clear exactly which biotic components in soil control the leaching process, but their sensitivity to toxicants is readily demonstrable. No other existing tests provide information on leaching, and there are few other good tests to examine soil processes. At some future time, however, the sensitive factor(s) which control the leaching process may be identified, thus providing the basis for a new bioassay which could then supplant the microcosm study.

b. Part of the concept of water quality criteria and its use of screening data is to establish MATC (maximum acceptable concentration) based on the assumption that if the most sensitive species are protected, all others species will be protected. If the results from a screening microcosm, therefore, are not unique relative to existing simpler tests, i.e., not routinely part of the minimum ecological data set, and if they are evaluated in the same qualitative manner as single-species test information, then they must indicate a greater sensitivity to a toxicant than the results from other well-established tests. For example, if a toxicant interferes with the metabolism of a special algal community in a microcosm at 10 times the concentration at which it reduces fish growth, then, from a regulatory point of view, an MATC to protect the fish (the assumed critical species in the environment) would also protect the algae. Thus, for relative ranking and worst-case analyses, a screening microcosm must demonstrate the existence of a more sensitive component of the ecosystem.

boundary conditions of an environmental sample, as often effected in a microcosm, the biogeochemistry becomes uncoupled from the ecosystem. Although this uncoupling may not eliminate any critical components or change the number and types of interactions, it could greatly upset the rates at which these interactions occur. Thus, the usefulness of a microcosm is not impaired, but if the controlling variables for the rates of these interactions are not understood, no attempt should be made to extrapolate the microcosm result quantitatively to the field.

A common example of the almost unavoidable uncoupling brought on by a microcosm study is the exclusion of higher trophic levels, such as herbivores and carnivores, from a microcosm. Several studies have shown that the effects of grazing on primary productivity may be substantial. Reductions in producer standing crops by a herbivore have caused increases in primary productivity (Cooper, 1973), and deposit-feeding amphipods have been shown to affect the productivity of sediment microflora significantly (Hargrave, 1970). Primary productivity of diatom communities is known to be increased by crayfish grazing (Flint and Goldman, 1975). With these types of potential uncouplings, it is precarious to extrapolate a microcosm result directly to the field.

Further evidence that a microcosm is unlikely to represent 100% of the ecosystem's biochemistry can be found in the spatial, and sometimes the temporal, assumption made in physically modeling a particular ecosystem (for example, the cross section of an estuarine ecosystem as shown in Figure 3). An assumption in modeling part of the ecosystem in a microcosm may be to establish a sediment/water system representing the average sediment surface area to water volume ratio of the bay (dotted line in figure). This assumption may be tenable for some studies. However, from the standpoint of exposure assessment in which a chemical may biodegrade much more rapidly in sediment than in water,

(multi-species test) are used. The key consideration is that a microcosm study provides the conceptual and experimental framework for developing a testable hypothesis and for recognizing and investigating the frequency distribution of the processes and component interactions operating within an ecosystem.

Several important factors can be cited in support of this approach. First, a microcosm, by design, isolates a community of some level of complexity which is representative of a portion of an ecosystem. Since the fundamental thermodynamic basis of ecosystems involves the generation of energy from the oxidation of degradable organic materials to immobilize inorganic nutrients produced from geochemical events external to the ecosystem, ecosystems are viewed as biogeochemical units that reflect the integration of a large variety of metabolic networks. A microcosm, therefore, will house a certain proportion of these networks, but not all. This is shown diagrammatically in Figure 2. The microcosm design and the assumptions applied to its operation will determine the extent of the biogeochemistry of an ecosystem which is captured in a microcosm. Thus, a particular microcosm may or may not harbor a great deal of the biogeochemistry of an ecosystem (size of the microcosm circles), and it may or may not reflect the true dynamics and interactions of an ecosystem (overlap into the ecosystem circle). In most microcosm studies, the circles will be large, indicating the presence of many metabolic networks found in nature, but will have lesser degrees of overlap, indicating limitation or exaggeration of the dynamics of the networks in the microcosm.

Rarely, if ever, would a situation occur as shown in Figure 2B, in which a single community or microcosm would account qualitatively and quantitatively for all the biogeochemistry of the ecosystem. By establishing arbitrary

it is not tenable because the chemical will disappear at a faster rate in shallower waters where its encounter with sediment will be more frequent. Thus, the microcosm results give a conservative estimate of fate because of this original assumption. It is a hydrodynamic problem in assessing fate, i.e., what is the expected distribution of the chemical among compartments varying degrees of biodegradation potential The microcosm should not provide information on overall distribution; this is the predictive job of a mathematical model. Instead, the microcosm should provide a broad view of the biodegradation potential of each component and the possible interactions contained therein.

Further biodegradation may be more rapid in and around rooted macrophytes, such as found in grass bed areas and adjoining salt marshes. Higher concentrations and activities of bacteria on the plant leaf surfaces in the root rhizosphere and in the associated detrital material may contribute significantly to the biodegradation of certain chemicals. The exposure of the chemical to these areas would again be dependent on the hydrodynamics of the estuarine system, and the exposure can be substantial. A microcosm designed to model only the more geographically dominant neritic component of the estuarine system would ignore this contribution from the plants. Thus, if this type of microcosm were used to study the fate of a chemical in an estuary, an erroneous estimation of the chemical's fate could be obtained. Great caution, therefore, should be exercised in extrapolating microcosm results directly to the field. The same argument holds true in many cases for toxic effect studies as well.

5. Role of Microcosms in Quantitative Assessments

Given these limitations on extrapolability, how in fact, is the microcosm effective in waste assimilatory capacity determinations The key may be found in studying a microcosm within the same theoretical framework that has been formulated for studying a natural ecosystem, particularly in reference to the concept of studying ecology by combining holism with reductionism (Odum, 1977). An ecosystem according to Heath (1979) is an array of components interacting cooperatively to form a complex unit through which energy, matter and information may flow. The behaviors of the individual components of a system are constrained and coordinated through the network design of the system. Some of the properties of the system arise not from the components themselves but from the specific set of interactions within the system. Thus, it is not possible to characterize a system only from a knowledge of the component parts. Since a reductionist approach to ecology, by its very nature of analysis, causes a disruption of this network design or set of interactions, it must be combined with a study-of-the-whole. As Schindler (1980) stated, the attempt to understand the state-of-the-whole should thus be a central focus in all ecosystem studies. Only after this state has been assessed or measured should an attempt be made to fractionate the system into component subsystems. Indeed, the state-of-the-whole should guide our definition of subsystems, rather than a priori definition of subsystems delimiting our recognition of properties of the whole.

Microcosms are considered by many investigators (Schindler, 1980; Hill and Weigert, 1980; Heath, 1979) to be a means of studying the state-of-the-whole in the laboratory. Although the microcosm is itself a component of the ecosystem due to its uncoupling from the field, as noted above, it is none the less a

6. Examples of the Quantitative Use of Microcosms

The dosing with the toxicant p-cresol of several man-made stream channels (located in Monticello, MN, and maintained by the EPA Environmental Research Lab, Duluth, MN, and Michigan State University) (Cooper et al., 1981) provided the opportunity to determine how accurately the fate of p-cresol could be predicted in the field streams. A microcosm study involving the fate of p-cresol was conducted to provide picture of the state-of-the-whole (Figure 4). Intact portions of the riffle and pool areas in the streams were transported to the microcosms in trays (36 cm diam, 10 cm high). A recirculation device completely mixed the water column (80 liters) and produced turbulence similar to that in the stream. The stream channel which was dosed with 8 parts per million (ppm) p-cresol was actually a closed recirculating loop; consequently, the microcosms, as a riffle-pool pair, could be maintained as closed systems. Since the stream was autotrophically based, diurnal dissolved oxygen profiles were used to calibrate the microcosm with the field. Invertebrate populations in the rocks and sediment were also used as calibration points. In both cases, good simulation of the stream was obtained in the microcosm (Pritchard, unpublished results).

The microcosms (riffle-pool pairs) were spiked with 8 ppm p-cresol, and the disappearance of the parent compound was followed by high-pressure, liquid chromatographic analysis. The result (Figure 5) is representative of the state-of-the-whole; the rate of disappearence of p-cresol is controlled by some unknown number of factors whose integration produces the microcosm result. No loss of p-cresol occurred in azoic microcosms.

It is important to keep in mind that the microcosm has little predictive value of it own. Since the microcosm is not a duplicate of the stream, the results of the studies have no quantitative bearing on the rate of

complex system that will contain much of the "network design" and system-level interaction of a natural ecosystem and can therefore be considered as a state-of-the-whole.

For the purposes of extrapolation of laboratory data to the field, the concepts of holism and reductionism must be combined. The state-of-the-whole should be established initially in the laboratory, using a microcosm; then, through a process of manipulation and disassemblage of that whole, the interworkings of the ecosystem can be understood. Basically, the whole should be broken into a group of subsystems; then the state-of-the-whole becomes a foundation around which to clarify the interactions and the rate-dependent processes of those subsystems. The subsystems are basically synonymous with the multispecies test represented in Figure 1. The relation of these subsystems to the whole is the critical experimental exercise because the subsystems most likely will: a) generate new experimental questions and b) produce insight into rates and system dynamics. The rates are crucial to extrapolation whether applied to toxic effects studies (rates of recruitment, rates of growth, reproductive rates, rates of metabolism rates of grazing, rates of feeding, etc.) or to fate studies (rates of transport, biodegradation rates, rates of photolysis, rates of bioaccumulation, rates of sorption, etc.). If rates can be studied, and the factors that control them investigated relative to the state-of-the-whole, then predictive ecosystem mathematical models can be developed and risk analysis performed. A possible use of microcosms can be to provide a "state-of-the-whole" for natural aquatic ecosystems. A specific fate study follows to illustrate how the "state-of-the-whole" can be manipulated and disassembled into subsystems (multispecies tests) to provide quantitative information on the factors controlling the fate of a chemical in aquatic system and on data for a mathematical model.

disappearance of p-cresol in the stream channel; therefore, only a qualitative judgment can be made of its fate in the stream. However, a quantitative extrapolation of laboratory data to the field is possible if the controlling variables which affect the compound's fate in the microcosm can be demonstrated. For this particular chemical, kinetic information about its biodegradation (specifically, rate constants) is needed.

The manipulation of the "state-of-the-whole" to understand more clearly the biological factors controlling the fate of p-cresol (Smith et al., 1978) indicated that abiotic processes minimally affect the fate of p-cresol. Our study compared the rate of degradation of p-cresol in microcosms containing only riffles and only pools. Figure 6 shows that the all-pool microcosm degraded p-cresol much slower than did the all-riffle microcosm. The degradation rate in the pool-riffle microcosm was intermediate. Clearly, the manipulation indicated that stream riffle areas were very important in the biodegradation of p-cresol. Since respiking of the microcosms produced similar degradation rates in all systems (Figure 6), it would appear that the contribution from the riffles is important in initiating degradation of p-cresol.

It was necessary to disassemble the state-of-the-whole into subsystems or multispecies tests to obtain more quantitative details. In microbial systems, mixed populations associated with water, sediment, rock surfaces and plant surfaces were readily separated from the microcosm and studied in shake flasks to determine their p-cresol biodegradation potential. Figure 7 shows the degradation rates of p-cresol in shake flasks containing components from the stream. Bacteria associated with rock surfaces were the most active degraders, whereas bacteria associated with the water were the least active.

The important consequence of these subsystem experiments is that degradation per unit mass, or rate constants, can be obtained, i.e., rates per liter of water, rates per rock, rates per gram of sediment, etc. The individual contribution of each of these rates can be established by determining the combination and integration required to simulate the microcosm results. If the approximate mass is known for each component in the field stream, and this rate information can be integrated, the rate of disappearance of p-cresol in the streams can be predicted. A mathematical model greatly facilitates this exercise. Preliminary efforts in this regard for the p-cresol studies have shown that the subsystem or multispecies test information is sufficient to predict results in the stream (as verified by its sufficiency to predict fate in the microcosms), and that the key controlling variables for the fate of p-cresol can be dissected by examination of subsystems.

It is interesting that knowledge of the activities of pure cultures (single species) of p-cresol-degrading bacteria, although readily isolated from the stream or microcosm, was insufficient to predict the rate of biodegradation of p-cresol in the stream. These isolated organisms, readily obtained from stream water samples, behave much differently when separated from their natural assemblages. Invaluable qualitative insight into microbial biodegradation mechanisms of p-cresol and the relationship of chemical structure to biodegradability was gained by using pure cultures of bacteria (Dagley and Patel, 1957; Hopper and Taylor, 1975; Buswell, 1975).

Single-species tests are excellent and invaluable qualitative measures of toxic effects, but provide inadequate information on which to predict dynamic consequences of toxicant stress, particularly at sublethal concentrations. An approach as outlined for a fate assessment, that is, starting with the state-of-the-whole and working toward simpler subsystems, should be undertaken to develop quantitative measures of toxic effects as

4. Limit to the Degree of Environmental Simulation in Microcosms

The means by which microcosms can aid in the extrapolation of laboratory data to the field or in determinations of waste assimilative capacity should be considered. Figure 1 indicates that microcosm results did not feed directly into waste assimilatory capacity determinations, i.e., extrapolation to field situations occurs in a more indirect manner. The reason for this approach lies in the fact that there are specific limits to the degree of environmental simulation possible in a microcosm and, consequently, limitations on the extrapolation of microcosm data. Our focus is on simulation of the field in a microcosm, rather than duplication, and there are consequently certain limits to the exactness that can be expected. Thus, the deviation from the norm and the degree of the acceptable diversion will be a function of the experimental question posed and the intended applications. Because of these limits, it is very difficult to make quantitative or one-on-one extrapolations of a microcosm result to the field. It is entirely unreasonable to assume, for example, that a microcosm result can be multiplied by some type of "expansion" factor and then equated to a field situation. At best, the microcosm is a qualitative indicator of phenomena, rates, and interactions which could occur in nature. The simulation capability of a microcosm merely enhances our confidence in the fact that the phenomena and reactions observed in the microcosm will more than likely occur in nature. Microcosm results alone disclose very little about how to predict quantitatively the dynamics of these phenomena and interactions in nature, particularly when considering the temporal and spatial variations in environmental parameters typical of many ecosystems. Predictions of dynamic events in nature will undoubtedly come from mathematical modeling efforts in which data from the analysis of processes and component interactions

required for determinations of a system's waste assimilative capacity. The ease of working with natural assemblages of microorgannisms in the laboratory obviously makes this approach useful. Although it is more difficult to perform toxicological studies on natural assemblages of plants and animals in the laboratory, it is nonetheless an effort that should be seriously considered in the future.

A potential example of this approach for effect studies can be projected with the benthic community settling system described by Hansen and Tagatz (1980). By working with field colonized sediment, the same experimental system can be developed as a microcosm. Structural and functional aspects of the benthic community can be measured and calibrated with the field. Good simulation in community structure has been shown by Flint and coworkers (1982). This laboratory microcosm thus provides a state-of-the-whole which can be perturbed with a toxicant. Manipulation of the whole and the development of subsystems can be carried out to determine the population dynamics of the benthic community and perhaps to pinpoint the toxicant response at both structural and functional levels. Experiments that examine variations in organic loading, recruitment, functional compensation, resilience to toxicant stress, changes in dominance patterns, etc. can be attempted to understand the dynamic aspects of the state-of-the-whole. Cores could also be taken from the microcosms to develop subsystems for further testing, particularly functional measures, such as dissolved oxygen patterns and Eh profiles (Flint et al., 1982). Although the cost and the problem of trying to study complex ecosystem processes in small containers are initially greater than single-species tests, the microcosm approach and acquisition of kinetic information about fate and effect responses should ultimately lead to a more reliable determination of waste assimilative capacity.

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Figure 1. Schematic diagram of possible information flow from laboratory test systems to risk assessments. Differences in tests are explained in the text. Thickness of the arrows indicates amount of information flow. Cross hatched areas represent current flow of information.

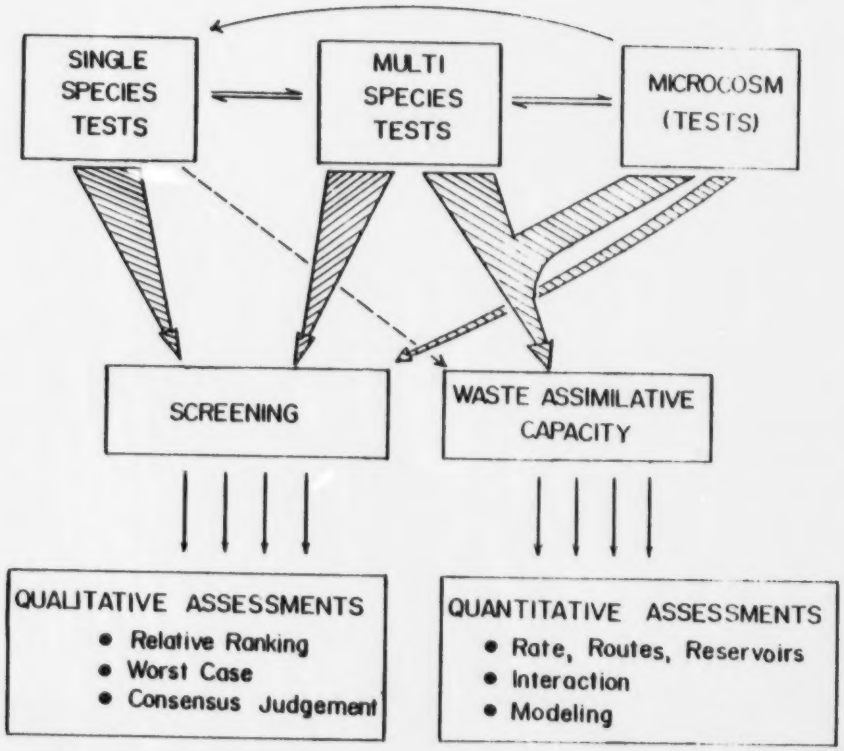
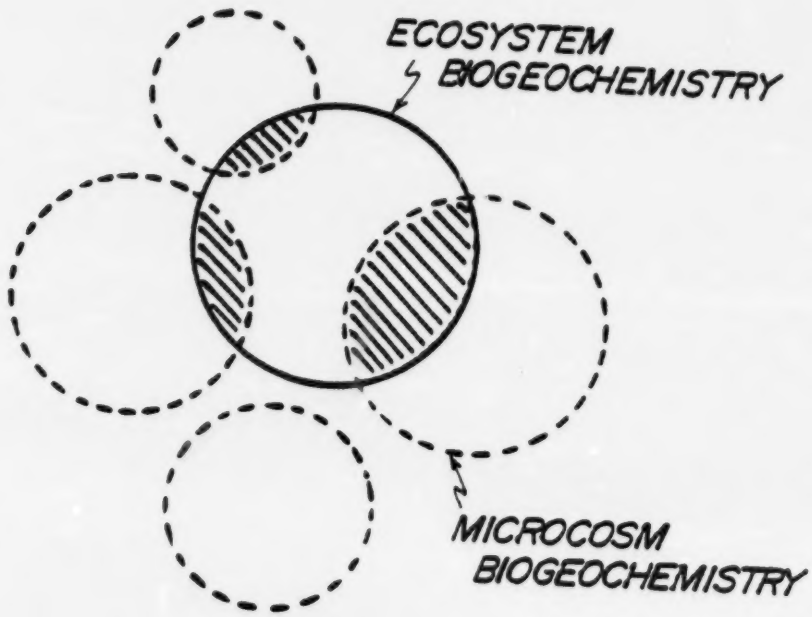

SINGLE SPECIES TESTS
MULTI SPECIES TESTS
MICROCOSM (TESTS)
SCREENING
WASTE ASSIMILATIVE CAPACITY
QUALITATIVE ASSESSMENTS
• Relative Ranking
• Worst Case
• Consensus Judgement
QUANTITATIVE ASSESSMENTS
• Rate, Routes, Reservoirs
• Interaction
• Modeling

Figure 2. Schematic diagram portraying possible interrelationship between the biogeochemistry of an ecosystem and various microcosms. Size of the microcosm circles indicates extent of the ecosystem's biogeochemistry housed therein. Overlap of the circles indicates similarities in rates of biogeochemical processes in microcosms and the ecosystems A and B represent possible examples of these interrelationships.

A.



B.

SIZE = QUANTITY
OVERLAP = RATES

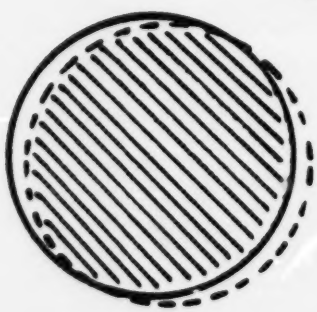


Figure 3. Diagrammatic cross section of a typical estuarine ecosystem. Dotted lined box represents portion of the ecosystem that could be modeled in a microcosm.

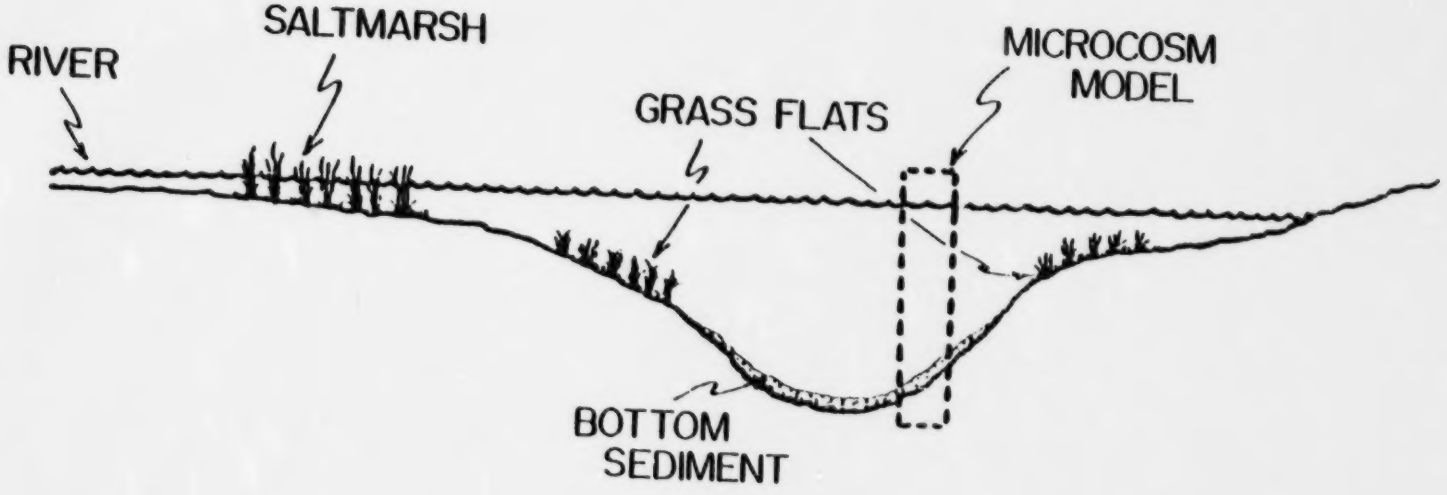

RIVER
SALTMARSH
GRASS FLATS
MICROCOSM
MODEL
BOTTOM
SEDIMENT

Figure 4. Schematic diagram of microcosms used to model the riffle and pool sections of the Monticello stream channels.

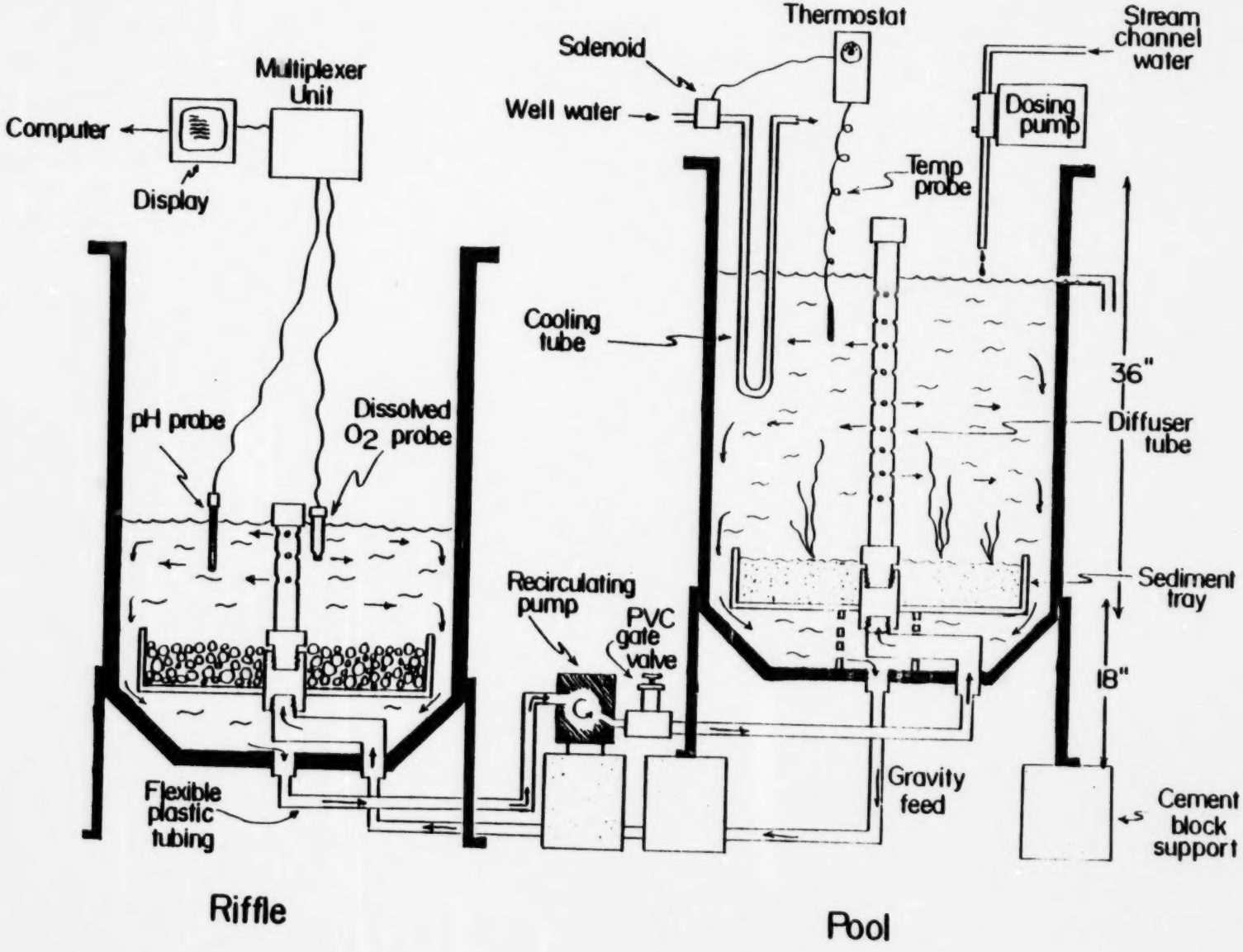

Computer
Display
Multiplexer Unit
pH probe
Dissolved O_2 probe
Flexible plastic tubing
Riffle
Solenoid
Well water
Thermostat
Stream channel water
Dosing pump
Temp probe
Cooling tube
36"
Diffuser tube
Sediment tray
18"
Recirculating pump
PVC gate valve
Gravity feed
Cement block support
Pool

Figure 5. Rate of disappearance of p-cresol in a riffle-pool microcosm. Microcosm was operated as closed continuously mixed reactor.

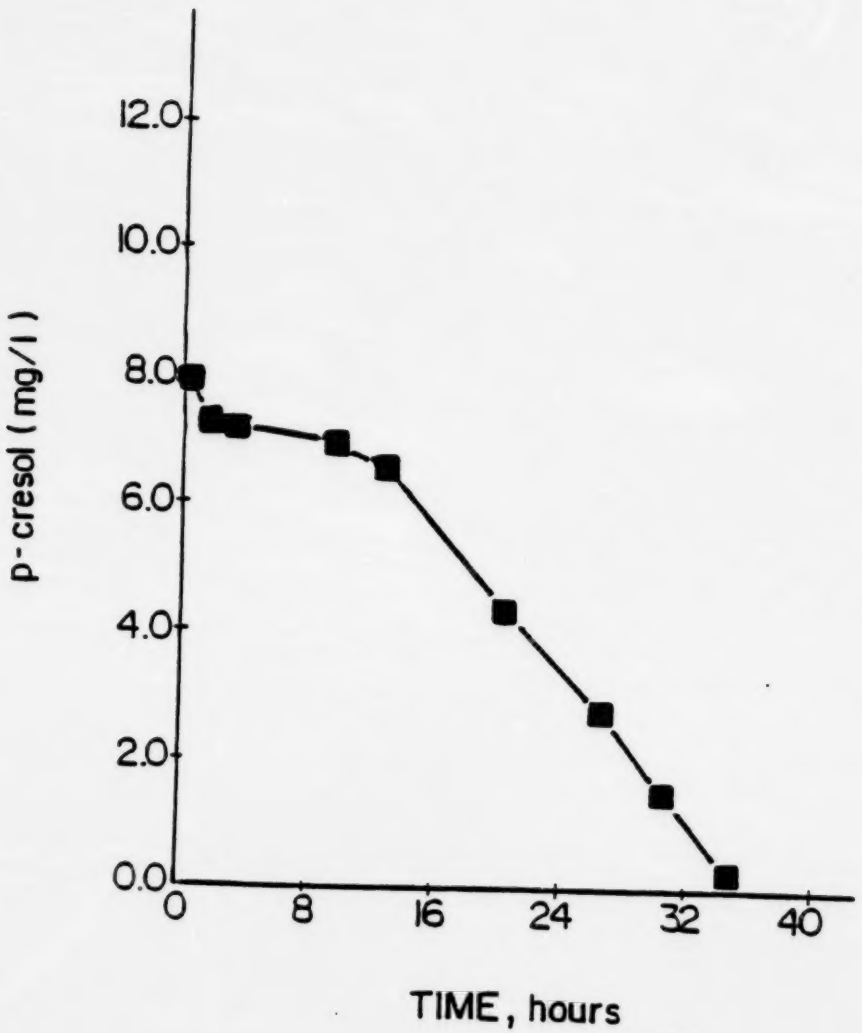

12.0
10.0
8.0
6.0
4.0
2.0
0.0
p-cresol (mg/l)
0
8
16
24
32
40
TIME, hours

Figure 6. Rate of disappearance of p-cresol from three types of microcosm sets; all riffles (●) all pools (o) and one riffle/one pool (◘). At hour 45 and 60, all three microcosms were respiked with p-cresol.

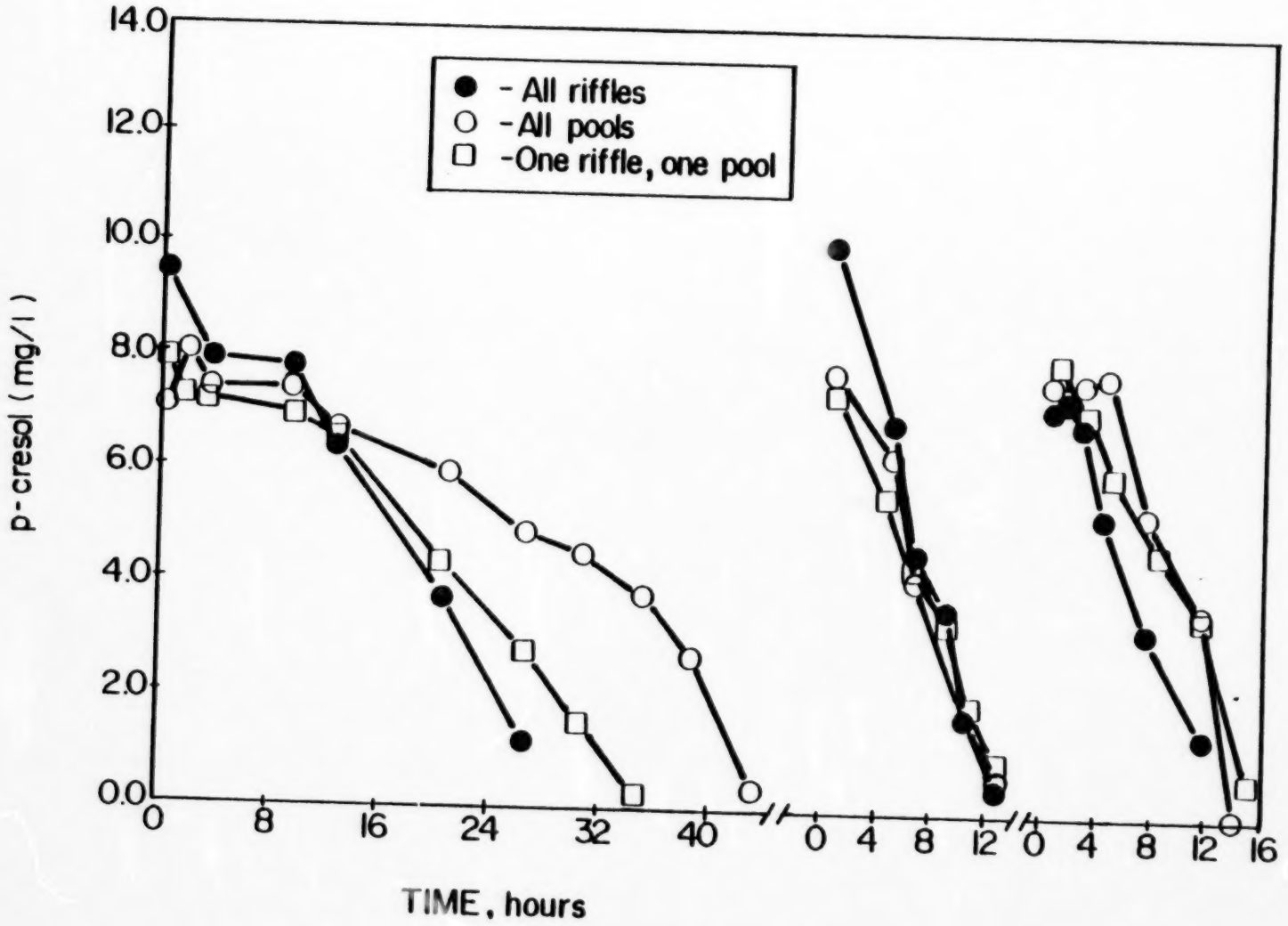
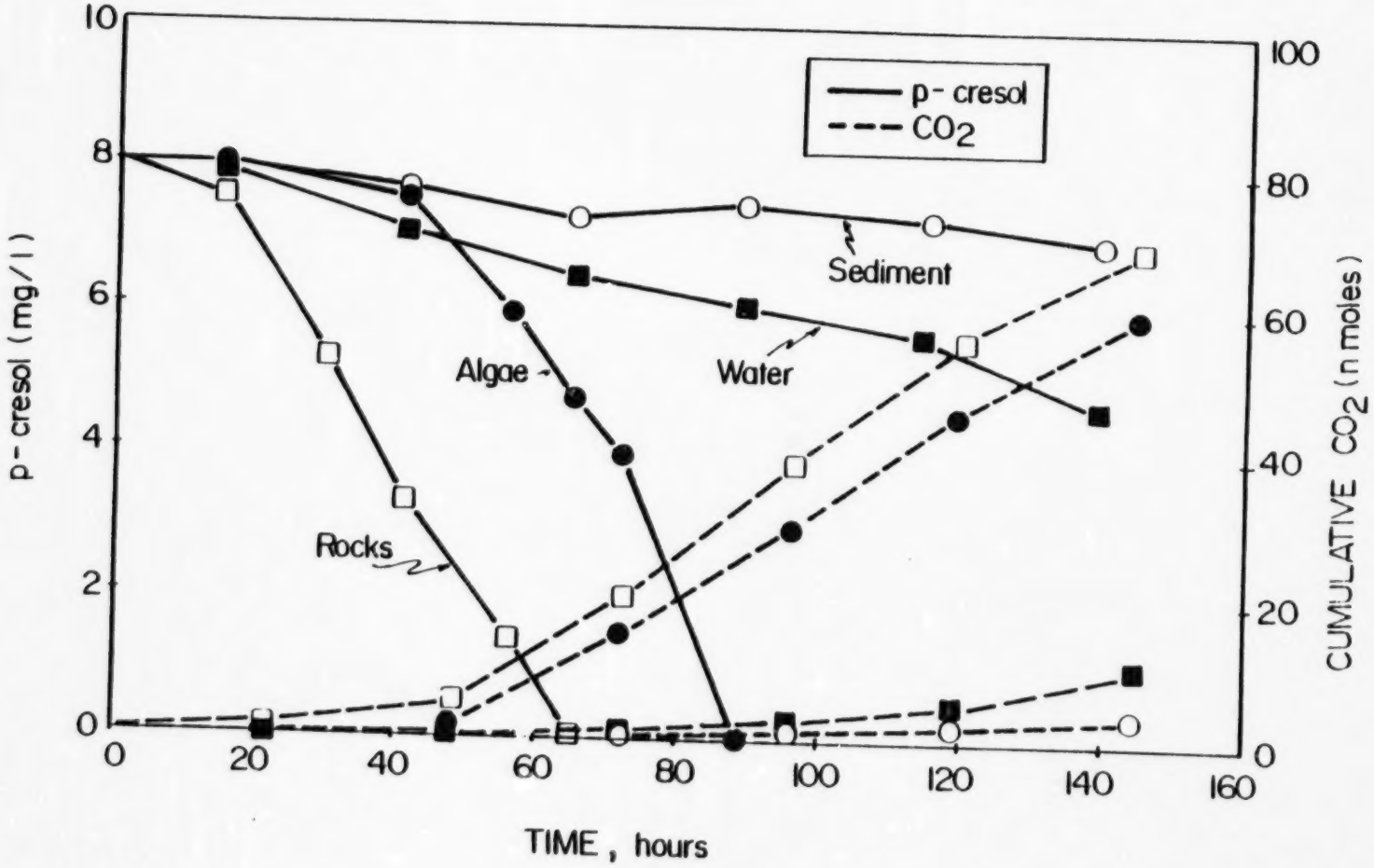

14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
p-cresol (mg/l)
● - All riffles
○ - All pools
□ - One riffle, one pool
0
8
16
24
32
40
0
4
8
12
0
4
8
12
16
TIME, hours

Figure 7. Disappearance (solid lines) and mineralization (dotted lines) rates of p-cresol in shake flask systems containing different components from the stream channels. For algae (Spirogyra 162 mg wet wt. per liter), sediment (340 mg wet wt. per liter) and rocks (seven, 1.4 mg dry wt. of periphyton per rock), components were washed 3 times with sterile stream water and then incubated in sterile stream water supplemented with p-cresol.


p- cresol
CO_2
Sediment
Water
Algae
Rocks
p- cresol (mg/l)
CUMULATIVE CO_2 (n moles)
TIME, hours
0
2
4
6
8
10
0
20
40
60
80
100
120
140
160